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High temperature grade magnetic diagnostic for COMPASS-U tokamak

A. Torres[1,2], T. Markovic[1,3], A. Havranek[1], K. Kovarik[1], V. Weinzettl[1], B. B. Carvalho[2] and H. Fernandes[2]

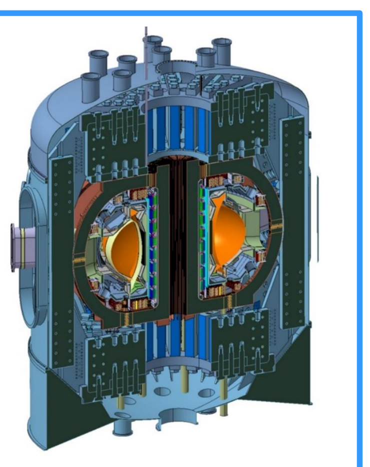
[1]Institute of Plasma Physics of the CAS, Prague, Czech Republic
[2]Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
[3]Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic

Contact: **torres@ipp.cas.cz**

COMPASS-U Tokamak

- Will replace COMPASS at IPP, Prague [1]
- First plasma expected by 2022
- Metallic first wall device
- Closed high density divertor
- Hot-wall operation **300 - 500 ºC**
- Passed Conceptual design review in October 2018

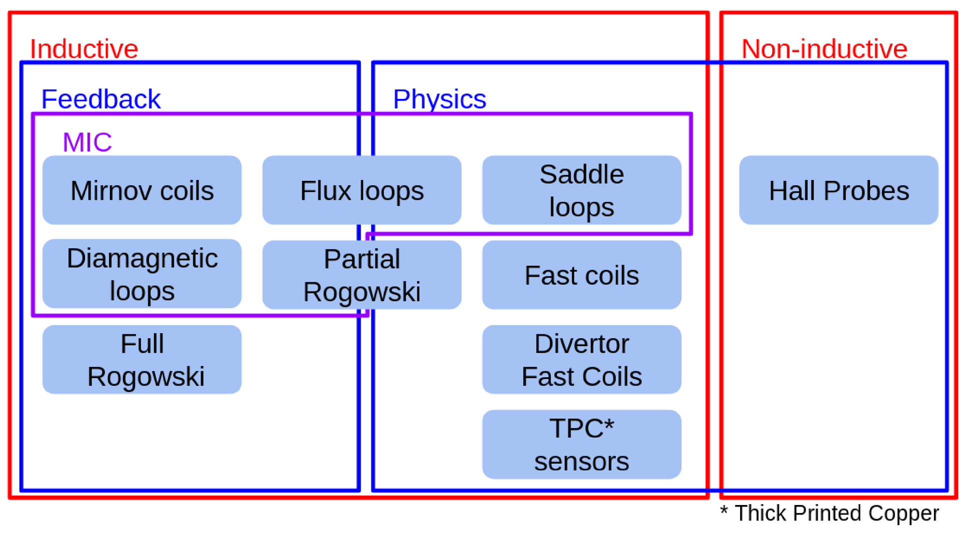
Parameter	Value
I_p [MA]	2
R_0 [m]	0.89
a [m]	0.27
B_0 [T]	5
NBI P_{aux} [MW]	4
ECRH P_{aux} [MW]	4
t_{pulse} [s]	<5



Focus on the handling of DEMO relevant, extreme plasma heat fluxes

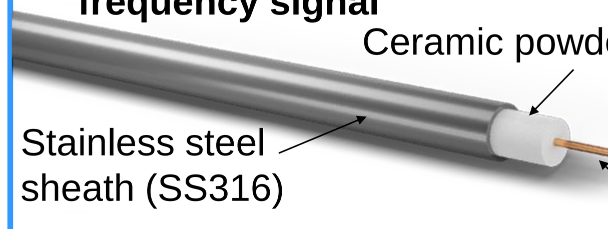
Magnetic diagnostics for Compass-U

- Beyond survivability, coils should provide reliable and accurate measurements at high temperatures (up to **500 ºC**) [2]
- Passed CDR in October 2019
- PDR under preparation

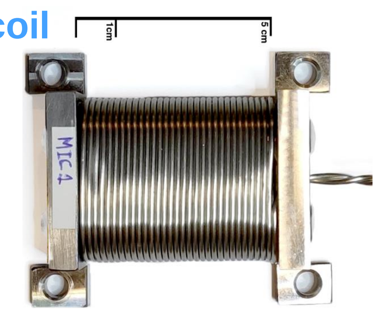


Mineral Insulated Cables (MIC)

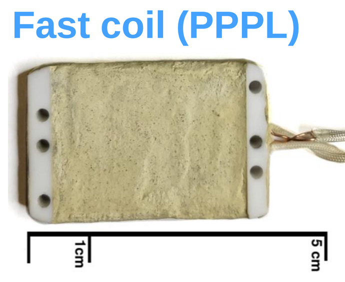
✓ Survivability of more than 700 ºC
× **Shields high-frequency signal**

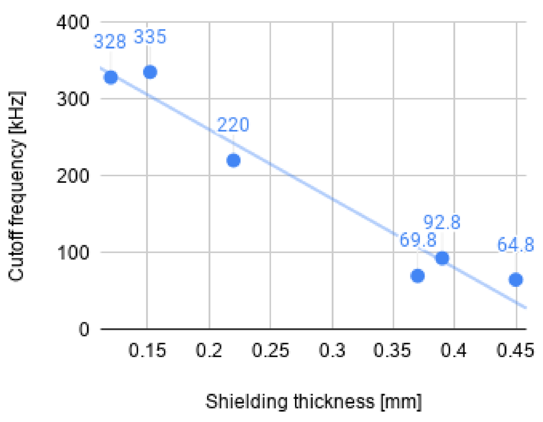


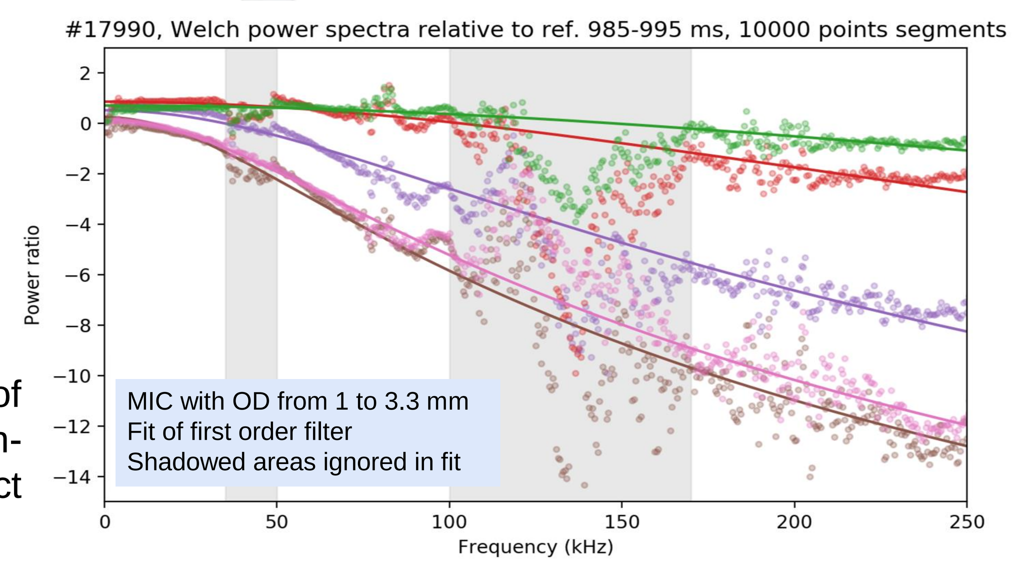
Mirnov coil



Fast coil (PPPL)



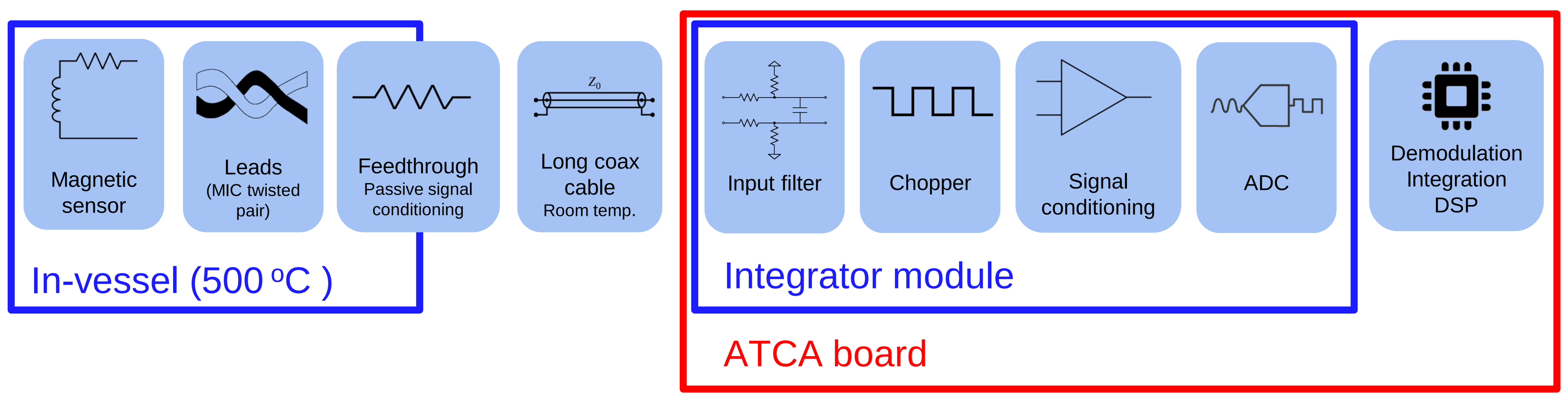




Tests on Compass – attenuation of different MIC flux loops versus non-shielded reference. Shielding effect comparable to first order filter. [3]

MIC with ticker shielding have worse frequency response

Full signal path

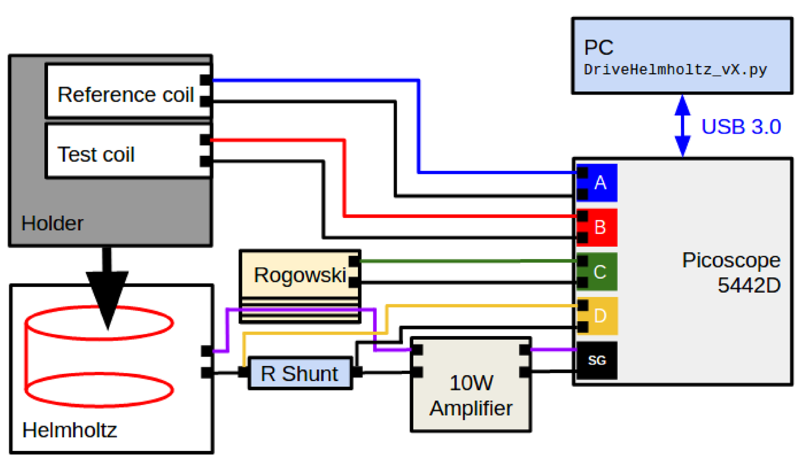


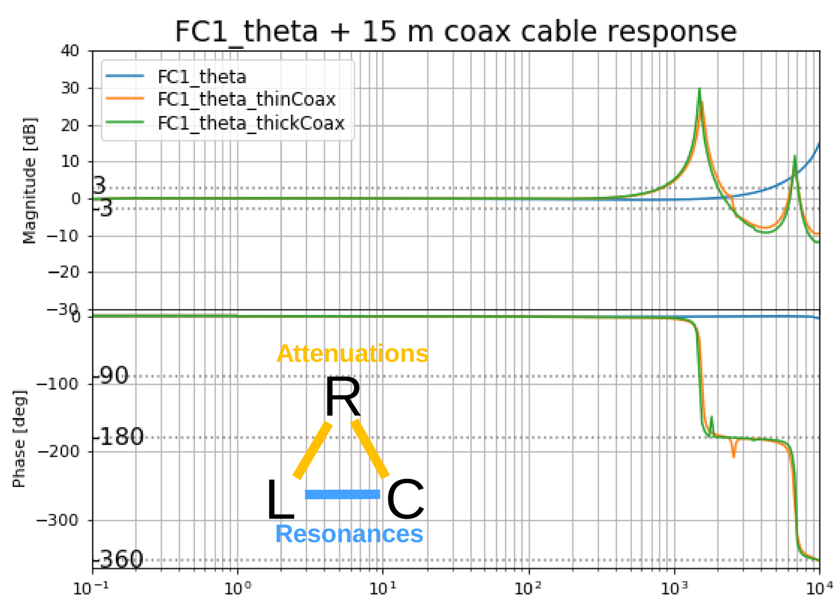
Measurement of pickup coils frequency response

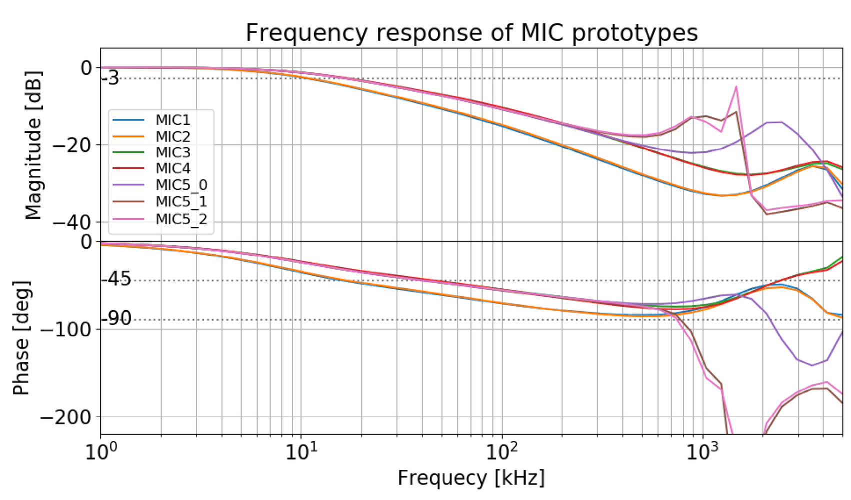
2 MIC coils that have a tradeoff in effective area and frequency response:

- **Double layer** S_{eff} = 410 cm²; F_c= 11 kHz
- **Single layer** S_{eff} = 175 cm²; F_c= 17 kHz

Fast coils resonances can be precisely modeled





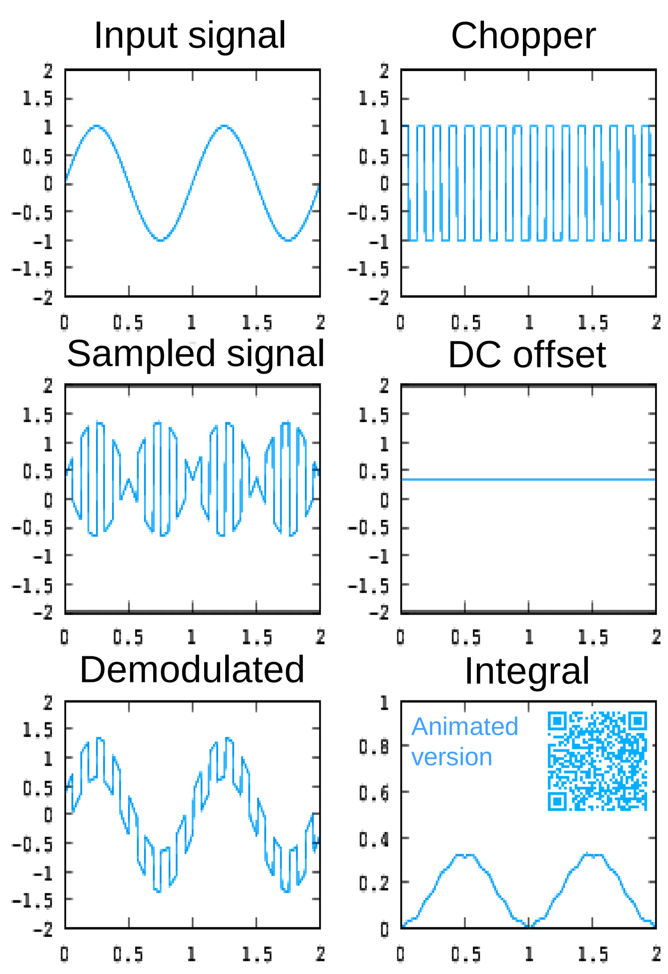


The knowledge of the frequency response of the full signal path allows its compensation using DSP and if not possible, the establishment of operating ranges and uncertainties

Digital integration

Digital integration with phase switching modulation has already demonstrated very low drift performance [4].

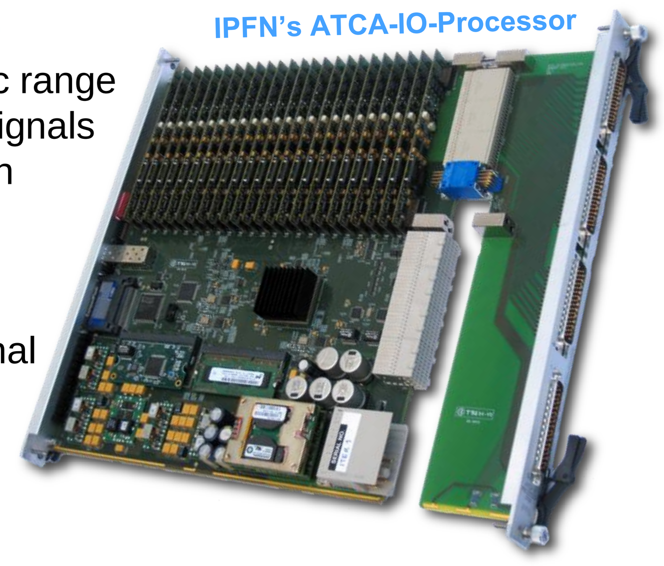
✓ 'Drift-less' integration for COMPASS-U timescale
✓ Real-time DSP
✓ Modular design
} scalability and easy maintenance



Input passive filter
✓ Reduces dynamic range of the magnetic signals
× Lowers bandwidth

A dual channel module architecture ensures that no signal is lost due to DC saturation.

IPFN's ATCA-IO-Processor



Phase modulation removes drift-inducing electronics offsets without affecting the integral

Preliminary digital integration tests on present COMPASS

- Very **low drift**, negligible for COMPASS-U timescale
  0.18 – 0.31 μV; 650 – 1120 μV s/h
- **Low noise** level measured after discharge:
  0.01 – 0.3 μV s

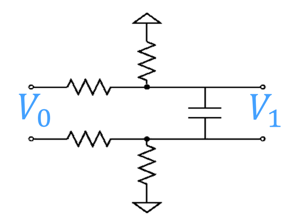
2 MSPS 18 bit ADC modules with chopper

Signal conditioning and frequency recovery

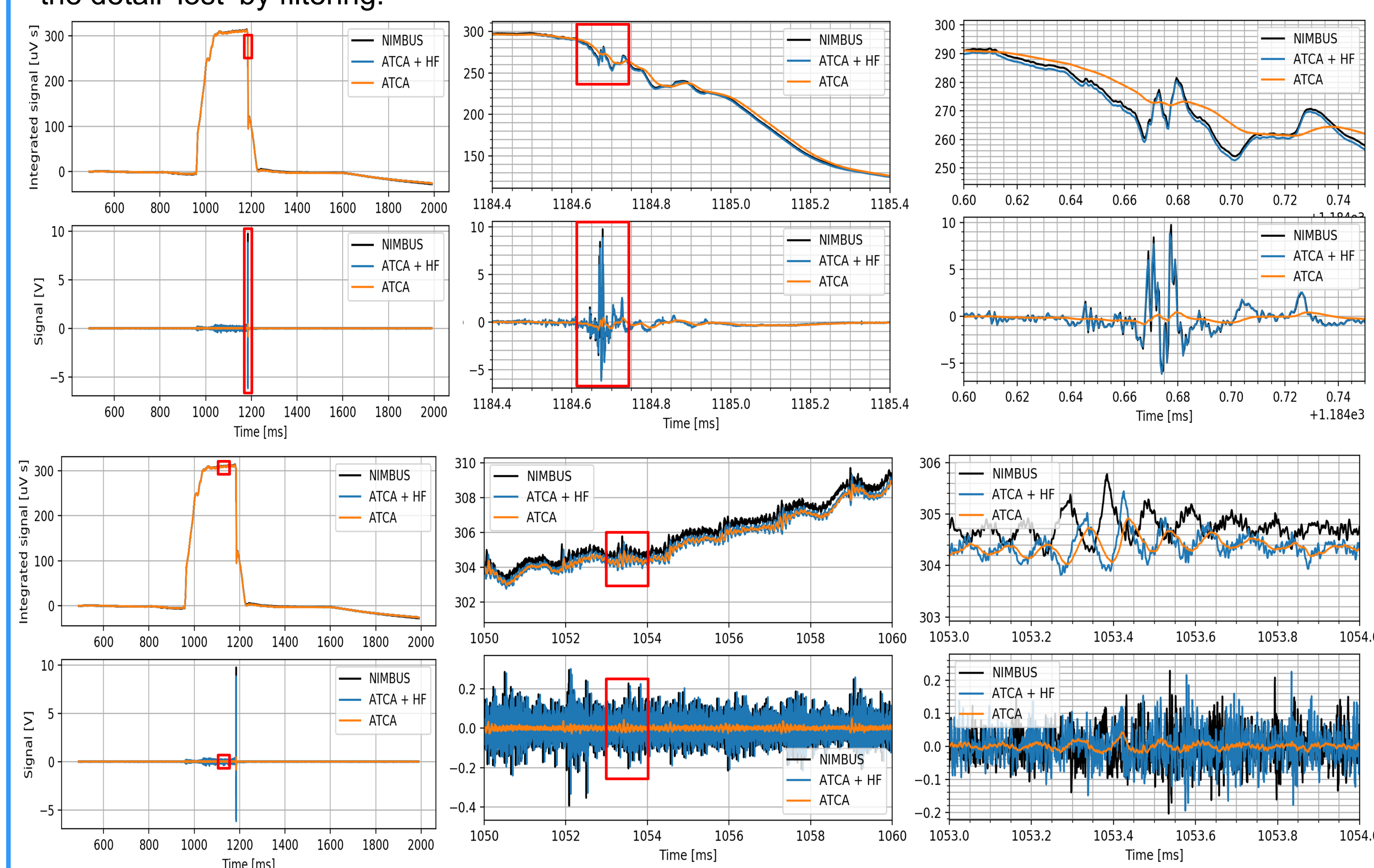
The input first order low pass filter acts as an integrator for high frequencies.

$H_{int} = \frac{1}{s}$; $H_{LP} = \frac{1}{1+\tau s}$ for $|\tau s| \gg 1 \Leftrightarrow f \gg f_c$, $H_{LP} \approx \frac{1}{\tau} H_s$

In fact, with the input low pass filter: $\Phi = \int V_0\, dt = \int V_1 dt + \tau V_1$ [5]



Mirnov coil signals acquired by **NIMBUS** and input filtered ATCA. Reconstructed signal recovers the detail 'lost' by filtering.



Recovery of high frequency components from filtered signal successful

Development for COMPASS-U

- Full frequency response characterization for MIC coils
- ADC module prototypes with 18 and 24 bit ADC, dual-channel architecture
- DSP algorithm for composition and signal integration
- Integration in COMPASS-U CODAC

References

[1] Panek R., et al., "Conceptual design of the COMPASS upgrade tokamak", Fusion Engineering and Design 123, 11-16 (2017).
[2] Weinzettl V., et al., "Constraints on conceptual design of diagnostics for the high magnetic field COMPASS-U tokamak with hot walls", Fusion Engineering and Design 146, 1703-1707 (2019).
[3] Torres A., et al., "Mineral insulated cable assessment for inductive magnetic diagnostic sensors of a hot-wall tokamak", Journal of Instrumentation 14, C09043 (2019).
[4] Batista A. J. N, "F4E prototype of a chopper digital integrator for the ITER magnetics", Fusion Engineering and Design 123, 1025-1028 (2017)
[5] Strait, E. J. , "A hybrid digital-analog long pulse integrator", Review of Scientific Instruments 68, 381-384 (1997)

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